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Heat balance and transfer in men and women exercising in hot–dry and hot–wet conditions*

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Sex-related differences in heat balance and transfer were studied in nine female and ten male heat-acclimatized subjects exposed to two hot–dry (HD) conditions (49°C, 20% rh; 54°C, 10% rh) and three hot–wet (HW) conditions (32°C, 80% rh; 35°C, 90% rh; 37°C, 80% rh). Exposures lasted 120 min: 10 min rest, 50 min walk, 10 min rest, 50 min walk. Walking speed was $1 \cdot 34\ m\ s^{-1}$ (level), and for 49°C, 20% rh, in addition, $1 \cdot 34\ m\ s^{-1}$, 5% grade. No sex-related differences were found in metabolic heat production (M), nor in heat exchange by radiation and convection ($R + C$) or evaporation (E), when expressed per unit body weight (wt). However, E per unit body surface area (A_D) was lower in females by 9–13% ($P < 0 \cdot 05$ in all HD conditions and for the 32°C, 80% rh condition) due to their lower M/A_D, and 4–6% lower $(R + C)/A_D$ in HD. Core-to-periphery heat conductance was similar in both sexes despite a lower core-to-skin temperature gradient for women in HD. It was suggested that women have an advantage over men in heat transfer particularly in HW because of their higher A_D/wt. The disadvantage of a high A_D/wt at high HD environmental temperatures is diminished by a higher skin temperature, thus reducing ($R + C$) heat gain. The net effect is to require lower evaporative cooling for women in both HW and HD environments.

1. Introduction

Women differ from men in several morphological parameters: their body fat content is higher (Bar-Or *et al.* 1969, Wilmore *et al.* 1977), they have a lower body weight, and they have a higher surface area-to-mass ratio (A_D/wt) (Fein *et al.* 1975, Nunneley 1978, Robinson 1942). Since metabolic heat production during exercise is related to body weight, and heat exchange with the environment is body surface area related, it is expected that the sexes will thermoregulate differently. It is known that females tolerate heat better than males in hot–wet (HW) environments, but worse than males in hot–dry (HD) environments (Hertig *et al.* 1963, Morimoto *et al.* 1967, Shapiro *et al.* 1980 a, Weinman *et al.* 1967). When heart rate (HR) and rectal temperature (T_{re}) were used as indices of heat tolerance, it was shown that in HD conditions both HR and T_{re} were higher for women than for men under the same heat load (Brouha *et al.* 1961, Fox *et al.* 1969, Hertig *et al.* 1963, Shapiro *et al.* 1980 a, Shoenfeld *et al.* 1978), while lower values were displayed for women under HW conditions (Shapiro *et al.* 1980 a, Weinman *et al.* 1967).

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Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70–25 and USAMRDC Regulation 70–25 on Use of Volunteers in Research.

A recent study suggested that women have a higher T_{re} in HD conditions because of a higher thermoregulatory set-point (Shapiro *et al.* 1980 a); this suggestion supports the findings of Roberts *et al.* (1977). However, when the body cannot reach thermoequilibrium as a result of a low evaporative cooling capacity of the environment (E_{max}), the women thermoregulated better than the men as a result of their higher surface area-to-mass ratio (A_D/wt) (Shapiro *et al.* 1980 a). Some authors have suggested that the high A_D/wt of the female would be a disadvantage when ambient temperature is above skin temperature (Fein *et al.* 1975, Nunneley 1978, Robinson 1942), since the heat gained by radiation and convection ($R+C$) is a direct function of skin surface area, (($R+C$) $=k\cdot A_D\cdot(T_a-\bar{T}_{sk})$, where T_a is the environmental temperature, $\bar{T}_{sk}$ the mean skin temperature, and k a constant depending on clothing insulation and air movement around the body). The significance of the higher A_D/wt for women is under controversy in the literature mainly because of a lack of quantitative information.

The purpose of this study was to evaluate heat balance and heat transfer in men and women while exercising under HW and HD conditions, in which air temperature was either above or slightly below skin temperature so that heat could be both lost or gained by $R+C$. In addition, the importance of differences in surface area-to-mass ratio for the sexes under these conditions was evaluated.

2. Methods

Nine female and ten male volunteer soldiers served as subjects. All subjects were totally informed with regard to experimental risk and gave their written consent. The physical characteristics of the females (mean ± S.E.) were: age, 22·0 ± 1·0 yr; height, 161·5 ± 2·3 cm; weight, 56·5 ± 2·6 kg; body surface area, 1·59 ± 0·04 m^2; and A_D/wt, 283·0 ± 5·7 $cm^2\,kg^{-1}$ while the males were: age, 21·1 ± 0·6 yr; height, 178·6 ± 2·1 cm; weight, 75·6 ± 4·2 kg; body surface area, 1·93 ± 0·06 m^2; and A_D/wt, 258·9 ± 6·5 $cm^2\,kg^{-1}$. All experiments were conducted during early spring months. Prior to the heat exposures all subjects underwent medical examination to determine their fitness for the study.

The 19 male and female subjects, dressed in T-shirts, shorts, socks and indoor shoes, were then concurrently acclimatized for 6 consecutive days by walking on a level motor-driven treadmill at 1·34 m s^{-1} for two 50-min periods with a preceding and intervening 10-min rest period, at 49 C, 20% rh, 1 m s^{-1} wind speed (Shapiro *et al.* 1980 b). After this acclimatization period, the subjects were exposed to six environmental and work load variations: a mild wet climate (T_a = 32 C, rh = 80%, P_a = 3·8 kPa, wet-bulb globe temperature, (WBGT) = 30·3 C), two hot wet climates (T_a = 35 C, rh = 90%, P_a = 5·1 kPa, WBGT = 34·0 C; T_a = 37 C, rh = 80%, P_a = 5·0 kPa, WBGT = 34·5 C) and two hot dry climates (T_a = 49 C, rh = 20%, P_a = 2·3 kPa, WBGT = 34·0 C; T_a = 54 C, rh = 10%, P_a = 1·5 kPa, WBGT = 34·2 C). Wind speed for all climates was constant at 1 m s^{-1}. The WBGT was similar for all four hot wet and hot dry environments. Each of these exposures lasted 120 min: 10 min rest, 50 min walk, 10 min rest, 50 min walk. Subjects walked at the same speed (1·34 m s^{-1}) on a level treadmill during these five combinations and in addition walked at 1·34 m s^{-1} on a 5% grade during a second exposure to the 49 C, 20% rh condition.

During all heat exposures, rectal temperature (T_{re}) was recorded from a Yellow Springs Instrument Co., Inc. rectal thermistor probe inserted ~ 10 cm beyond the anal sphincter. Skin temperatures were monitored with a three-point thermocouple skin harness (chest, calf and forearm) and mean weighted skin temperature ($\bar{T}_{sk}$) was calculated according to Burton (1935). Using a Hewlett-Packard 9825 A Calculator

and 9862 A Plotter on-line during the experiments, both $\bar{T}_{sk}$ and T_{re} were plotted for each subject at approximately 2-min intervals. Heat storage (S) was calculated as follows: $S = 0.965\ (0.8\Delta T_{re} + 0.2\Delta \bar{T}_{sk})$ in W kg^{-1}. Heart rate was measured by radial artery palpation during the rest periods and after each 25 min of walking. *Ad lib.* drinking was encouraged. At the end of the first rest period and at the end of each walking period, 2-min expired air samples were collected in Douglas bags; the volume was measured in a Collins Spirometer and converted to standard environmental conditions (STPD), and the O_2 and CO_2 concentrations were measured with an Applied Electrochemistry Model S 3A O_2 analyser and Beckman LB-2 infrared CO_2 analyser. A time weighted average metabolic rate (M) was calculated as 0·17 of the resting value plus 0·83 of the mean of the two level walking values. In the case of walking uphill the external work was deducted from the measured metabolic rate (Pandolf *et al.* 1977). Total body weight losses were determined from pre- and post-walk measurements on a K 120 Sauter precision electronic balance (accuracy of $\pm$ 10 g) for calculation of sweat rate. Sweat rate ($\dot{m}_{sw}$) was determined from weight loss, adjusted for water intake, urine output, and respiratory and metabolic weight losses. The metabolic weight loss ($\dot{m}_r$) and the respiratory water loss ($\dot{m}_e$) were calculated according to Mitchell *et al.* (1972) as: $\dot{m}_r = 0.53\ \dot{V}O_2$ in g min^{-1} and $\dot{m}_e = 0.019\ \dot{V}O_2\ (44 - P_a)$ in g min^{-1}, where P_a is the ambient water vapour pressure (mm Hg) and $\dot{V}O_2$ is the O_2 consumption (l min^{-1}). The net sweat rate was expressed as the theoretical evaporative cooling power (1 Watt = 1·486 g h^{-1}), and normalized both per kg body weight and per m^2 surface area.

The $\bar{T}_{sk}$ and $\Delta(T_{re} - \bar{T}_{sk})$ were calculated as mean values from the individual 2-min values starting from the eleventh minute of the exposure (the beginning of the first walking period) to the end of the exposure. Conductance was calculated as an average value for the last 20 min (when the subjects were either in or close to thermoequilibrium) as: Conductance $= (M - S)/(T_{re} - \bar{T}_{sk})$ in W m^{-2} °C^{-1}. The radiative and convective heat exchange with the environment ($R + C$), the evaporative cooling power needed to maintain thermoequilibrium (E_{req}) and the maximal evaporative cooling power of the environment (E_{max}) were calculated according to Givoni and Goldman (1972). In the calculation of $R + C$ and E_{max}, the actual $\bar{T}_{sk}$ for each 2 min interval was used, and then the 2 min values were averaged to determine the mean value for the 120 min exposure. The evaporative heat loss (E) was calculated as $E = M + (R + C) - S$, and the heat loss by evaporation of sweat alone (E_{sw}) as $E_{sw} = E - E_{res}$, where E_{res} is the respiratory heat loss $E_{res} = 0.0023\ M\ (44 - P_a)$ (Mitchell *et al.* 1972). The efficiency of sweat evaporative cooling (η) was determined as $\eta = E_{sw}/\dot{m}_{sw}$ with $\dot{m}_{sw}$ corrected as indicated above for respiratory and metabolic weight losses. Criteria for terminating any heat exposure were a heart rate of 180 beats min^{-1} during exercise or 140 beats min^{-1} during rest, and or a T_{re} above 39·5 °C, dizziness, nausea, or dry skin.

2.1. *Statistical treatment*

Most variables were evaluated by use of a mixed design of two factors, with one factor being the two groups (male and female) and the other being the treatment (environmental conditions) which both groups received. If a significant F-value was found ($P < 0.05$), critical differences were analysed by Tukey's procedure to locate the significant mean differences.

3. Results

When the components of the heat balance equation were expressed in terms of power per unit body weight (W kg^{-1}), no differences between the sexes were

Table 1. Comparison of heat balance components of the various climatic conditions (mean ± S.E.) for males (M) and females (F).

	Hot dry						Hot-wet					
T_a C, rh %	49 C, 20%		54 C, 10%		49 C, 20%		32 C, 80%		35 C, 90%		37 C, 80%	
Treadmill grade %	0		0		5		0		0		0	
	M	F	M	F	M	F	M	F	M	F	M	F
$R+C$, W m^{-2}	128·00	123·00	188·00	178·00*	139·00	133·00	−23·00	−18·00	−6·00	−2·00	15·00	17·00
	3·00	2·00	2·00	1·00	2·00	2·00	1·00	2·00	1·00	1·00	1·00	1·00
$R+C$, W kg^{-1}	3·31	3·48	4·86	5·05	3·60	3·78	−0·60	−0·52	−0·16	−0·07	0·40	0·47
	0·12	0·09	0·09	0·14	0·08	0·10	0·04	0·06	0·02	0·03	0·02	0·02
M, W m^{-2}	169·00	152·00*	171·00	152·00*	232·00	201·00*	172·00	146·00*	179·00	154·00*	174·00	151·00*
	5·00	4·00	3·00	3·00	7·00	4·00	4·00	5·00	4·00	4·00	4·00	4·00
M, W kg^{-1}	4·37	4·28	4·43	4·31	5·98	5·69	4·44	4·11	4·64	4·36	4·51	4·26
	0·12	0·10	0·11	0·11	0·12	0·12	0·12	0·12	0·16	0·09	0·18	0·10
E_{sw}, W m^{-2}	277·00	254·00*	333·00	295·00*	340·00	313·00*	135·00	119·00*	144·00	134·00	159·00	145·00
	6·00	5·00	4·00	7·00	7·00	4·00	5·00	7·00	4·00	3·00	4·00	3·00
E_{sw}, W kg^{-1}	7·15	7·19	8·61	8·36	8·77	8·84	3·50	3·36	3·73	3·78	4·13	4·11
	0·20	0·15	0·20	0·25	0·19	0·14	0·12	0·15	0·12	0·11	0·18	0·13
$\dot{m}_{sw}$, W m^{-2}	314·00	291·00	368·00	368·00	402·00	351·00	179·00	145·00*	355·00	287·00*	360·00	256·00*
	12·00	10·00	15·00	16·00	21·00	10·00	11·00	9·00	27·00	14·00	17·00	20·00
$\dot{m}_{sw}$, W kg^{-1}	8·12	8·23	9·48	10·41	10·39	9·95	4·58	4·07	9·16	8·10	9·29	7·23*
	0·33	0·37	0·35	0·51	0·56	0·39	0·21	0·21	0·69	0·42	0·43	0·58
η	0·89	0·88	0·92	0·82	0·86	0·90	0·78	0·84	0·43	0·47	0·45	0·59*
	0·03	0·04	0·03	0·04	0·03	0·08	0·04	0·05	0·03	0·02	0·02	0·04

* $P < 0·05$ (for M versus F differences).

found for metabolic heat production, radiative and convective heat exchange, and therefore in the E values either for HD or HW conditions (table 1). However, for these same data, analysis per unit surface area ($W\,m^{-2}$) yielded sex-related differences as illustrated in figures 1 and 2 and tables 1 and 2. The metabolic rate was significantly lower ($P < 0{\cdot}05$) for the females in all conditions (10–13% in HD and

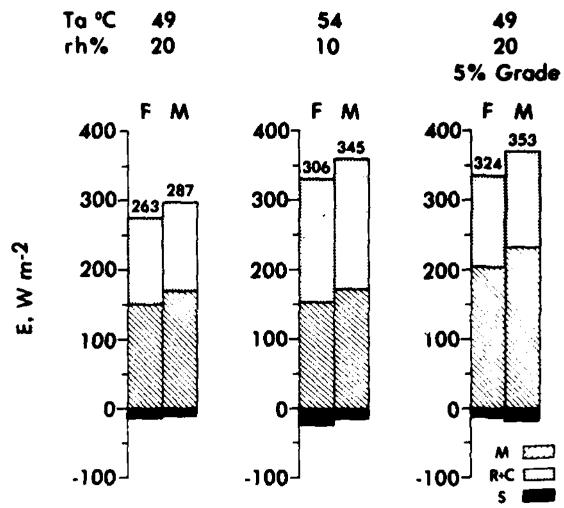

Figure 1. Comparison of mean evaporative heat loss (E), ($E = M + (R + C) - S$) between males (M) and females (F) in three hot dry conditions (49 C, 20% rh walking level; 54 C, 10% rh walking level; 49 C, 20% rh walking 5% grade). The numbers at the top of each column represent the E values. The area ($R + C$ and S) above and below the zero point represent whether these values are to be added or subtracted from M.

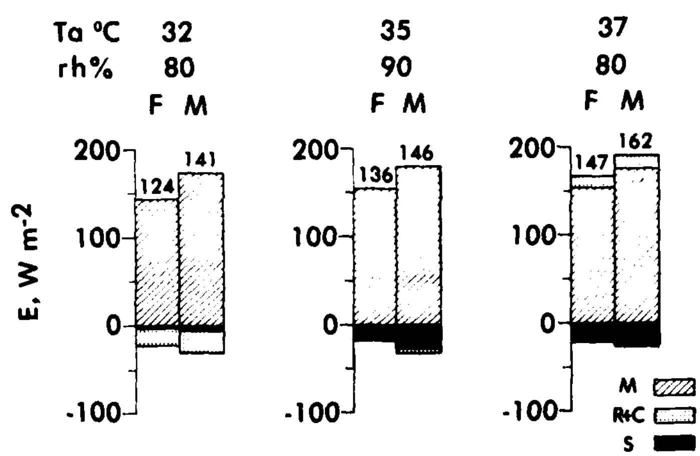

Figure 2. Comparison of mean evaporative heat loss (E), ($E = M + (R + C) - S$) between males (M) and females (F) in three hot wet conditions (32 C, 80% rh; 35 C, 90% rh; 37 C, 80% rh). The numbers at the top of each column represent the E values. The areas ($R + C$ and S) above and below the zero point represent whether these values are to be added or subtracted from M.

Table 2. Comparison of heat transfer parameters in the various climatic conditions (mean ± S.E.) for males (M) and females (F).

	Hot dry						Hot wet					
T_a C, rh %	49 C, 20%		54 C, 10%		49 C, 20%		32 C, 80%		35 C, 90%		37 C, 80%	
Treadmill grade %	0		0		5		0		0		0	
	M	F	M	F	M	F	M	F	M	F	M	F
$\bar{T}_{sk}$, C	35·90	36·40	36·00	36·30	35·70	36·30*	34·20	33·80	35·90	35·50	36·20	36·00
(mean of 11 120 min)	0·10	0·20	0·20	0·20	0·20	0·20	0·20	0·20	0·10	0·10	0·10	0·10
$T_{re} - \bar{T}_{sk}$, C	1·74	1·31	1·43	0·67*	2·13	1·60**	3·40	3·77	2·01	2·22	1·92	1·90
(mean of 11 120 min)	0·18	0·19	0·14	0·14	0·27	0·17	0·15	0·18	0·07	0·09	0·06	0·06
Conductance,	107·00	105·00	114·00	116·00	126·00	129·00	51·00	40·00	82·00	63·00	89·00	73·00
$W m^{-2} C^{-1}$ (last 20 min)	10·00	10·00	12·00	13·00	17·00	11·00	3·00	2·00	5·00	5·00	4·00	5·00
E_{req}, $W m^{-2}$	297·00	267·00*	362·00	329·00*	350·00	308·00*	149·00	129·00*	172·00	152·00*	188·00	166·00*
	5·00	6·00	4·00	5·00	7·00	4·00	4·00	7·00	4·00	4·00	4·00	3·00
E_{max}, $W m^{-2}$	439·00	431·00	524·00	503·00	404·00	399·00	197·00	168·00	116·00	95·00	137·00	122·00
	6·00	6·00	7·00	7·00	9·00	7·00	5·00	6·00	3·00	4·00	3·00	3·00
E_{req} E_{max}	0·68	0·62	0·69	0·65	0·87	0·77	0·76	0·78	1·49	1·62	1·38	1·36
	0·02	0·02	0·01	0·02	0·03	0·02	0·03	0·07	0·04	0·09	0·04	0·04
$E_{req} - E_{max}$, $W m^{-2}$	−142·00	−164·00	−163·00	−174·00	−54·00	−91·00*	−48·00	−40·00	56·00	56·00	52·00	43·00
	9·00	11·00	9·00	11·00	14·00	8·00	8·00	12·00	4·00	5·00	5·00	4·00

* $P < 0·05$ (for M versus F differences). ** $P < 0·06$.

13–15% for HW). The $R+C$ was found to be 4–5% lower for the women in HD conditions, but significantly lower only for the 54 C, 10% rh condition. In humid conditions, $R+C$ was equal for both sexes when the value was positive (37 C, 80% rh), but for the two HW conditions with negative $R+C$ (32 C, 80% rh; 35 C, 90% rh) a trend for higher $R+C$ heat dissipation was found for men, although these differences were not statistically significant ($P>0{\cdot}05$). The E_{sw}, which reflects the combined effects of M and $(R+C)$, was significantly lower ($P<0{\cdot}05$) for the women in all HD conditions and also for the HW condition at 32 C, 80% rh (9–13%). Women also displayed lower E_{sw} in the other two HW conditions, but these were not significantly lower. The $\dot{m}_{sw}$ was found to be significantly lower ($P<0{\cdot}05$) for the females (20–30% lower) for the HW environments as illustrated in figure 4. No significant differences in $\dot{m}_{sw}$ were found for the HD conditions as illustrated in figure 3. No differences in sweat efficiency (η) were found between the sexes in HD conditions, but the efficiency was higher for females in all HW conditions although significantly higher only in the most severe HW condition (37 C, 80% rh) as presented in table 1.

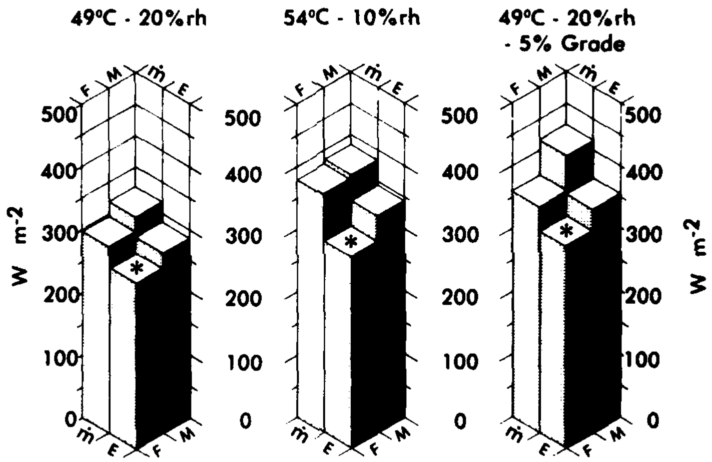

Figure 3. Comparison of mean sweat rate ($\dot{m}$) and evaporative heat loss (E) between males (M) and females (F) in three hot dry conditions (49 C, 20% rh walking level; 54 C, 10% rh walking level; 49 C, 20% rh walking 5% grade). Significant difference between sexes indicated by an asterisk.

An analysis of the heat transfer parameters (table 2) showed a trend for higher $\bar{T}_{sk}$ in HD environments for the females (0·3–0·6 C), with the difference being significantly higher ($P<0{\cdot}05$) only in the most severe exercise condition (49 C, 20% rh, 5% grade). Also, a trend of lower $\bar{T}_{sk}$ values for females prevailed in the HW conditions. The $T_{re}-\bar{T}_{sk}$ gradient was significantly lower for women in two of the HD conditions (not significant for 49 C, 20% rh, 0% grade), but there were no differences between the sexes in any of the HW conditions. The conductance, which ranged from 129 W m^{-2} C^{-1} in the most severe exercise HD condition to 40 W m^{-2} C^{-1} for 32 C, 80% rh, was found to be similar for both sexes. The demand for evaporative cooling rate to maintain thermoequilibrium (E_{req}) was significantly lower (10–14%) for the women under all conditions. However, no significant differences between the sexes were found for E_{max}

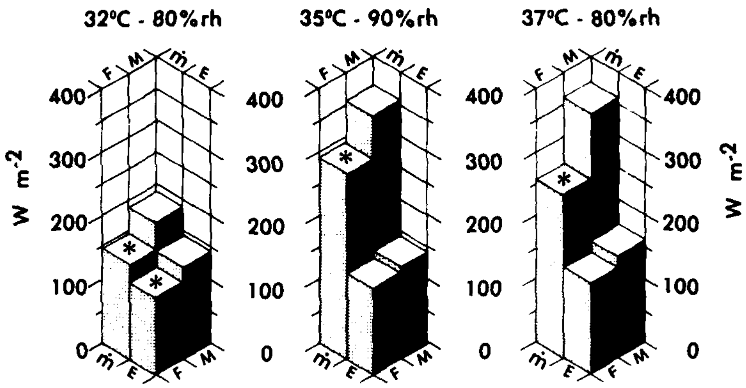

Figure 4. Comparison of mean sweat rate ($\dot{m}$) and evaporative heat loss (E) between males (M) and females (F) in three hot wet conditions (32 C, 80% rh; 35 C, 90% rh; 37 C, 80% rh). Significant difference between sexes indicated by an asterisk.

nor for the index E_{req}/E_{max}. The thermoregulatory forcing function ($E_{req}-E_{max}$) suggested a higher surplus cooling power for females in HD conditions (significant only for 49 C, 20% rh, 5% grade) and no difference in HW conditions.

The comparisons between the sexes in heat balance components and in heat transfer parameters are summarized in table 3. Women appear to have lower heat gain from the environment (lower $R+C$), as well as lower metabolic heat production and therefore have lower E_{sw} and E_{req} when all these values are calculated per unit surface area. Compared to men, the women's mean skin temperature ($\bar{T}_{sk}$) tends to be higher in HD and lower in HW conditions. Their core-to-skin temperature gradient is smaller than the males in HD conditions (equal in HW), but their conductance is essentially the same. Women are also seen to have a higher cooling surplus ($E_{req}-E_{max}$) under HD conditions.

Table 3. Summary of sex-related trends in heat transfer under hot dry and hot wet climates.

	Hot-dry	Hot-wet
$R+C$	= or ↓	= or ↑
M	↓	↓
E_{sw}	↓	↓
$\dot{m}_{sw}$	= or ↓	↓
η	=	↑
$\bar{T}_{sk}$	↑	= or ↓
$T_{re}-\bar{T}_{sk}$	↓	=
Conductance	=	= or ↓
E_{req}	↓	↓
E_{max}	=	=
E_{req}/E_{max}	=	=
$E_{req}-E_{max}$	↓	=

=, No difference. ↓, Females are lower than males. ↑, Females are higher than males.

4. Discussion

The major objective of this study was to evaluate sex differences in heat balance and transfer for various climatic conditions. For this purpose, three HD and three HW conditions were chosen. For the HD conditions the initial environment for evaluation was 49°C and 20% rh, from which the total heat load was increased once by elevating the ambient temperature to 54°C so that $(R+C)$ was increased by 50%, and once by increasing the metabolic heat production by 50% (walking on a 5% grade instead of on the level). For the HW conditions, the first condition (35°C, 90% rh) was chosen such that the T_a was close to the $\bar{T}_{sk}$. Thus, $(R+C)$ would be minimal and the WBGT would be similar to that of the HD conditions. The other two HW conditions were chosen to produce either a small positive $R+C$ (37°C, 80% rh) or a small negative $R+C$ (32°C, 80% rh).

The difference in body size between the sexes, with a lower body weight and surface area but a higher surface area-to-mass ratio for women, is well known (Nunneley 1978), and is consistent with our sample, which represents a young military population (White 1978). Thus, a major methodological problem arose involving whether to express the heat balance components in units of power per body weight or per surface area. We observed similar results for both sexes when the heat balance parameters were expressed per unit body weight; in contrast sex-related differences were found when these parameters were analysed per unit surface area.

For a variety of reasons, it would seem more logical to compare these heat balance values when they are presented per unit body surface area. Of the two heat gain components M and $(R+C)$, only the first (M) relates heat production to proportion of body mass, while the other $(R+C)$ is surface area related. Since heat dissipation is proportional to the surface area, and the crucial problem in hot environments is heat dissipation, it would seem preferable to use heat balance values per surface area as expressions to normalize differences between individuals.

The conclusive terms for heat dissipation are the E_{sw}, which is the actual heat dissipation provided by sweat evaporation, and the E_{req}, which denotes the required evaporative cooling power for thermoequilibrium. In this study, both E_{sw} and E_{req} were lower for the females than for the males (9–14%) under all conditions when expressed per surface area. However, the difference in E_{sw} was significantly lower in the HW conditions only for 32°C, 80% rh. Examination of the two main components of E_{sw} and E_{req} (M and $R+C$) showed that these differences were mainly due to the lower metabolic heat production of the females (as expected since the females weighed less and the metabolism per unit body weight was similar for both sexes). However, the heat production was 'spread' over a proportionately higher surface area in the females, i.e. the differences in heat production are greater than the differences in surface area. According to the literature (Fein *et al.* 1975, Nunneley 1978, Robinson 1942), the other main component of E_{sw} and E_{req}, which is $R+C$, might be a disadvantage for females in HD conditions due to their higher A_D/wt, and therefore higher surface area available for absorbing heat from the environment by radiation and convection when air temperature is much above skin temperature. Our findings showed that the higher A_D/wt for the females was not a major disadvantage since they gained similar heat by radiation and convection per unit body weight as the males, but gained 4–5% less per unit surface area. The latter was found to be significant in the most severe HD condition (54°C, 10% rh), where the greatest disadvantage for a higher A_D/wt would be expected. The higher $\bar{T}_{sk}$ for the females exhibited in these HD environments appears to be responsible for the lower $R+C$ gain than would be expected. Since $R+C$ is

proportional to the $T_a - \bar{T}_{sk}$ difference, increasing $\bar{T}_{sk}$ would effectively decrease $R + C$ heat gain.

The higher skin temperature for the females under HD conditions would decrease the T_{re} to $\bar{T}_{sk}$ gradient, which is a major factor in transferring heat from the core to the periphery, resulting in an increased conductance (Nadel 1977). In this study, despite the above mentioned decrease in the T_{re} to $\bar{T}_{sk}$ gradient, a similar conductance was found for both sexes. These findings can be related to the lower M/A_D for the females and the ability to conduct the same amount of heat with a lower gradient using a proportionately higher surface area.

Under the HW conditions where $(R + C)$ was less important, the females showed a trend for a lower $\bar{T}_{sk}$, higher T_{re} to $\bar{T}_{sk}$ gradient, and lower conductance than the males; however, it was only a trend, without any significant differences. Under the same HW environmental conditions the females better suppressed the non-evaporative sweat as shown by a lower $\dot{m}_{sw}$ and higher η, both differences significant for the 37 °C, 80% rh condition. This phenomenon was discussed extensively in a previous paper (Shapiro *et al.* 1980 a).

The E_{req}/E_{max} ratio, which is related to per cent of skin wettedness when the index is below 1 and represents sweat dripping from the skin when it is close to or above 1 (Givoni and Goldman 1972), can be used as a rough index of heat distress in hot environments. This ratio was found to be similar for both sexes under all six conditions and was found to express similar environmental comfort or discomfort for men and women under HD and HW conditions. Values of this index, along with the thermoregulatory forcing function $(E_{req} - E_{max})$ and the efficiency of sweat evaporative cooling (η) suggest a better overall state for the females; they have higher surplus cooling ability under HD climates (lower $E_{req} - E_{max}$; $P < 0.05$ for 49 °C, 20% rh, 5% grade) and also a better suppression of non-evaporative sweat (higher η) under HW climates ($P < 0.05$ for 37 °C, 80% rh).

It is suggested that the sexes have qualitatively similar heat balance and heat transfer characteristics. The differences are basically quantitative, where the females' higher surface area-to-mass ratio is a decided advantage in the various hot wet environments. In hot dry conditions where $(R + C)$ is a major factor, the physiological mechanism which protects women against the expected excessive heat gain by convection and radiation due to their higher A_D/wt is their increased skin temperature.

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Les différences liées au sexe en ce qui concerne l'équilibre et le transfert thermiques ont été étudiées chez 9 sujets féminins et 10 sujets masculins acclimatés au chaud et exposés à deux conditions chaudes-sèches (49 °C et 20% d'h.r.; 54 °C et 10% d'h.r.) et à trois conditions chaudes-humides (32 °C, 80% d'h.r.; 35 °C, 90% d'h.r.; 37 °C, 80% d'h.r.). La durée des expositions était de 120 min: 10 min de repos, 50 min de marche, 10 min de repos, 50 min de marche. La vitesse de marche était de 1,34 m s^{-1} (niveau horizontal) et pour 49 °C, 20% d'h.r., en plus, une pente de 5%. On n'a pas observé de différences liées au sexe, en ce qui concerne la production de chaleur métabolique (M) et l'échange de chaleur par radiation et convection ($R + C$) ou évaporation (E) exprimés par unité de poids corporel (wt.). Cependent E exprimé par unité de surface corporelle (A_D) était plus bas chez les femmes d'environ 9 à 13% ($p < 0{,}05$ dans toutes les conditions chaudes-sèches et dans la condition 32 °C, 80% d'h.r.), ce qui est dû à leur rapport M/A_D plus bas et à leur

rapport $(R+C)/A_D$ plus bas de 4 à 6% en condition chaude-sèche. La conductance calorique noyau-périphérie était la même dans les deux sexes en dépit d'un gradient thermique noyau-peau plus bas chez les femmes en condition chaude-sèche. On pense que les femmes présentent un avantage sur les hommes dans le transfert de chaleur en condition chaude-humide, à cause de leur rapport A_D/wt plus élevé. Le désavantage d'un A_D/wt au températures ambiantes chaudes-sèches est diminué par une température cutanée plus élevée, ce qui réduit le gain de chaleur $(R+C)$. L'effet net est de requérir un refroidissement plus bas par évaporation chez les femmes dans les ambiances chaudes-humides et chaudes-sèches.

Geschlechtsspezifische Unterschiede des Wärmehaushaltes und des Wärmeüberganges wurden an 9 weiblichen und 10 männlichen hitzeakklimatisierten Vpn untersucht, die zwei heiß-trockenen (HT: 41 °C, 20% r.F., 54 °C, 10% r.F.) und drei heiß-feuchten (HF): 32 °C, 80% r.F.; 35 °C, 90% r.F.; 37 °C, 80% r.F.) Bedingungen ausgesetzt waren. Die Expositionszeiten betrugen 120 min: 10 min Ruhe, 50 min Gehen, 10 min Ruhe, 50 min Gehen. Gehgeschwindigkeit: 1,34 m s^{-1} (eben) und für 41 °C, 20% r.F. zusätzlich 1,34 m s^{-1}, 5% Steigung. Es ergaben sich keine geschlechtsspezifischen Unterschiede für die metabolische Wärmeproduktion (M), den Wärmeaustausch durch Radiation und Konvektion ($R+K$) oder Schweißabgabe (S), wenn auf das Körpergewicht (K) normiert wurde. S bezogen auf die Hautoberfläche (HO) war bei Frauen um 9–13% geringer ($p<0{,}05$) für alle Ht-Bedingungen und für 32 °, 80% r.F.) wegen ihres niedrigeren M/HO und 4–6% niedriger für $(R+K)$/HO in der ht Bedingung. Der Wärmetransport vom Kern zur Peripherie war für beide Geschlechter gleich bis auf einen niedrigeren Kern-Peripherie-Temperaturgradienten für Frauen unter HT-Bedingungen. Es wurde vermutet, daß Frauen gegenüber Männern einen Vorteil beim Wärmetransport in HT-Bedingungen wegen ihres höheren HO/K aufweisen. Der Nachteil eines hohen HO/K bei hohen HT-Umgebungstemperaturen wird gemildert durch eine höhere Hauttemperatur, die die $(R+K)$ Hitzeaufnahme reduziert. Das Ergebnis ist die Forderung nach niedriger Kühlung durch Wasserverdampfung für Frauen sowohl unter HF und HT-Umgebung.

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